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ORIGINAL RESEARCH

The relationship between arterial pressure of carbon dioxide ($PaCO_2$) and end tidal CO_2 ($PECO_2$) during hypothermic cardiopulmonary bypass (CPB)

Vadood Norouzi[1], Mohammad Hasanpour[1*], Sanaz Fouladi[1]

ABSTRACT

Background: Physicians have always wanted to perform exact medical tests in non-invasive ways. During a cardiac surgery, after the onset of cardiopulmonary bypass, the patient's ventilation along with the patient's heart rate could stop, and the task of the two vital organs is transferred to the pulmonary heart system, which acts to ensure the patient's ventilation at defined intervals in the patient's arterial gas analysis. This study was done to determine the relationship between $PaCO_2$ and $PECO_2$ in cardiopulmonary bypass (CPB).

Methodology: In a cross-sectional study, a total of 30 patients referring to the heart surgery department of Ardabil City Hospital, who would undergo coronary artery bypass grafting without other illness, were included in the study. Arterial blood samples were taken, and the result was reported through the arterial blood gas device in the operating room. The $PaCO_2$ was compared with $PECO_2$. Data were analyzed by statistical methods in SPSS version 22.

Results: Of all patients, 17 (56.67%) were males and 13 (43.33%) were females. The mean age of patients was 60 ± 11 years with an age range of 35–78 years. The mean of $PaCO_2$ was 36.5 ± 4.13 mmHg and the mean of $PECO_2$ was 31 ± 6.4 mmHg. The fresh gas flow (FGF) was 1.9 ± 0.7. There was a positive and significant correlation between FGF and $PaCO_2$ and also between FGF and $PECO_2$.

Conclusion: Results showed that there was a significant relation between arterial PCO_2 and oxygenator exhausted PCO_2 during hypothermic CPB.

Keywords: Carbon dioxide, oxygenator, cardiopulmonary bypass, arterial pressure.

Introduction

Doing exact medical tests with non-invasive methods were always welcomed by physicians and patients. Measuring the saturation of blood oxygen by pulse oximetry and capnography in recovery and intensive care units has expanded more in recent years and it has become an appropriate substitute for an arterial blood sample that alone can provide useful information about the patient [1,2].

The basis of this test was to measure the amount of carbon dioxide in the exhalation air that normally is about 3–3.5 mmHg lower than the saturation of blood carbon dioxide. During cardiac surgery after the beginning of cardiopulmonary bypass, the patient's ventilation along with the patient's heart rate was stopped and the task of these two vital organs was devoted to the lung-heart machine and analysis of arterial gas was done to ensure the patient's ventilation rate at specified intervals. The analysis of arterial gas (carbon dioxide) was performed at intervals 20 minutes and there was no accurate knowledge of the amount of carbon dioxide in the intervals between measurements. no accurate information was available on the levels of blood carbon dioxide. Patient's ventilation during cardiac surgery was done by an oxygenator which was a part of the device. Oxygen was passed through the flowmeter to the oxygenator and oxygen and carbon

Correspondence to: Mohammad Hasanpour
*Department of Anesthesiology, Faculty of Medicine, Ardabil University of Medical Sciences, Ardabil, Iran.
Email: m.hasanpour@arums.ac.ir
Full list of author information is available at the end of the article.
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dioxide exchange was carried out there and after the gas exchange the remainder of this gas was exhausted from the oxygenator and discharged into the environment. The term oxygenator is used to describe blood gas exchange device and CO_2, O_2, and nitrogen values are regulated by the functions of this device [3].

Oxygenators are divided; into two groups; using more than 6 hours or longer and using less than 6 hours, which was called cardiopulmonary bypass (CPB) [4].

The use of the heat exchanger adjusts the normal temperature variation during CPB that in primary types of oxygenator are impartible to the device. Oxygenators are available in two hard (non-collapsible) or soft (collapsible) types. The ultimate oxygenation ability is gas transfer, purification of light, and the escape of gases of anesthesia [5].

As mentioned the primary oxygenator was complex and it needed direct contact with the blood. Engineering performed by C. Waltan Lilleher from the University of Minnesota in 1950 made bubble oxygenators cheap and available and the new device was made with simple equipment which was sufficient for the goals of advanced heart surgery, easy use, and they also allowed expansion of surgery to other centers (other than special centers). However, bubble oxygenators could not be used for all surgeries and were only used in short-term procedures. By improvement in safety and biocompatibility of membrane oxidants, it is estimated that almost 1 million devices are used annually worldwide [6].

Oxygenators were designed for short-term use in unconscious patients and the overall level of gas exchange in the oxygenator was just a fraction of gas exchange in natural lungs (0.6–4 *vs* 70 in the normal lung). Also, engineering in the oxygenators has caused a secondary flow that breaks the laminar stream to mix up blood without surfacing oxygen closer to the exchange space [7].

Oxygenators relieved these restrictions by increasing the length of the blood flow through the blood stream and so the gas exchange time increases (250,000 in oxygenator against 200 microns in the normal lung). Oxygenators can be vented with different percentages of O_2 (21%–100%) and the ventilation is carried out through the stream of gas from the flowmeter. The choice of each oxygenator for each CPB process is based on the patient's metabolic need that is usually determined by the patient's age, body size, and body composition [8]. The aim of this study was to investigate the relationship between the arterial pressure of carbon dioxide ($PaCO_2$) and end tidal CO_2 ($PECO_2$) during hypothermic CPB.

Subjects and Methods

This cross-sectional study was carried out on 30 patients who were candidates for Coronary artery bypass grafting (CABG) in Ardabil city Hospital in 2017. Patients' demographic information including age, gender, history of previous illness, history of drug use, and education was completed by a checklist. Patients visited a day before surgery and the order of premedication was placed with 0.3 mg/kg promethazine, half an hour before the transfer to the operating room with 0.1 mg/kg morphine; and after obtaining patient's satisfaction the transfer to the operating room took place, then under anesthesia with thiopental sodium 5 mg/kg, pancuronium at 0.1 mg/kg, fentanyl at 4 µg/kg, and lidocaine 1.5 mg/kg were given. The process continued under anesthesia with isoflurane 1.5%–1%, oxygen 100%, and morphine 0.1 mg/kg. After removing the smooth veins of the foot, preparing internal mastoid artery and prescribing heparin at 350 units per kg, the patients were subjected to a pulmonary artery pump. The duration of the bypass was fixed on an hour. From these patients, an arterial blood sample was taken, and the result was recorded via arterial blood gas device in the operating room. The CO_2 pressure from the oxygenator was recorded by capnograph. The oxygenator connected to the CPB was disposable and the cardiac output was set up by an anesthetist while using the pump. There was no confounding factor for CO_2 pressure (Including fever from underlying diseases such as hyperthyroidism and malignant hyperthermia). Data were analyzed using descriptive and analytical statistical methods in SPSS version 22. $p < 0.05$ was considered as significant.

Patients up for CABG with a normal status of coagulation tests (including partial thromboplastin time, prothrombin time, and platelet count) and an ejection fraction of more than 40% were included in the study. Whereas patients with pulmonary obstruction and valvular disease, ejection fraction of less than 40%, history of previous pulmonary edema, severe underlying diseases such as chronic renal failure, emergency patients, and anemia patients were excluded from the study.

Results

Seventeen (56.67%) of the patients were males and 13 (43.33%) were females. The average age of patients was 60 ± 11 years with an age range of 35–78 years (Table 1). There was no significant difference between the average $PaCO_2$ with 31.4 ± 5.36 and $PECO_2$ with 31.3 ± 6.6 mmHg. There was a positive and significant correlation between $PaCO_2$ and $PECO_2$ (r = 0.87 and p = 0.001). There was a positive and significant correlation (r = 0.435 and p = 0.06) between fresh gas flow (FGF) and $PaCO_2$ (Figure 1). There was a positive and significant correlation (r = 0.37 and p = 0.04) between FGF and $PECO_2$ in CPB (Figure 2).

Also, the average FiO_2 in this study was 70.1 ± 5.8. There was no significant correlation between FiO_2 and $PaCO_2$. The correlation between CO with $PaCO_2$ (r = 0.558 and p = 0.001) was positive and significant (Figure 3). The correlation between $PECO_2$ and $PaCO_2$ with r = 0.576 and p = 0.001 was also positive and significant (Figure 4).

Table 1. *Demographic data of patients.*

Variables		*n*	%
Age	44–35	3	10
	54–45	5	16.7
	64–55	10	33.3
	≥ 65	12	40
	Mean ± SD	60 ± 11 years	
Sex	Male	17	56.7
	Female	13	43.3
Occupation	Housekeeper	11	36.7
	Non-employee	10	33.3
	Farmer	3	10
	Employee	6	20
Education	Illiterate	12	40
	Elementary	7	23.3
	High school	6	20
	University degree	5	16.7

SD, standard deviation.

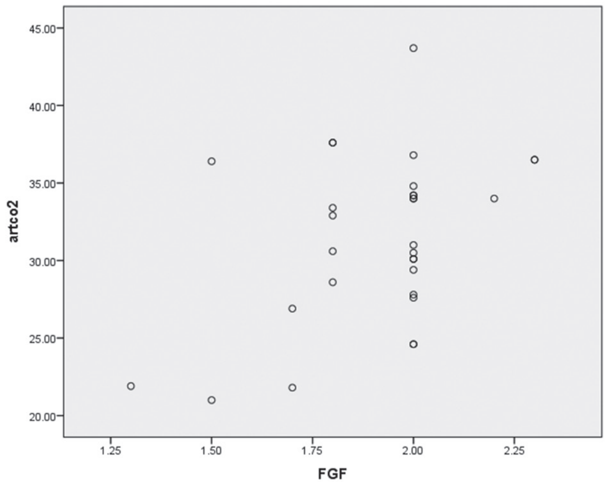

Figure 1. *Correlation between FGF and $PaCO_2$.*

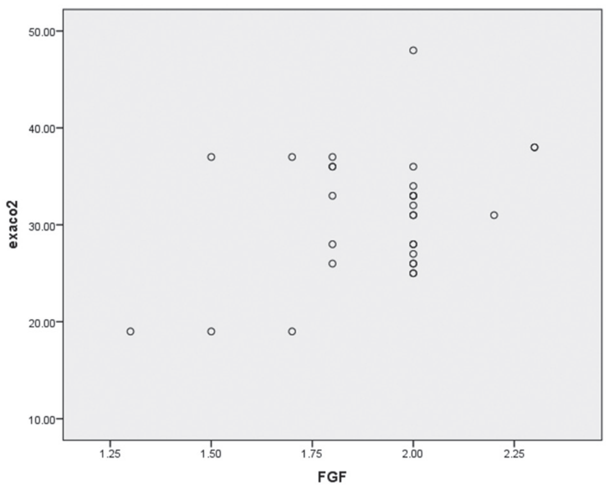

Figure 2. *Correlation between FGF and $PECO_2$.*

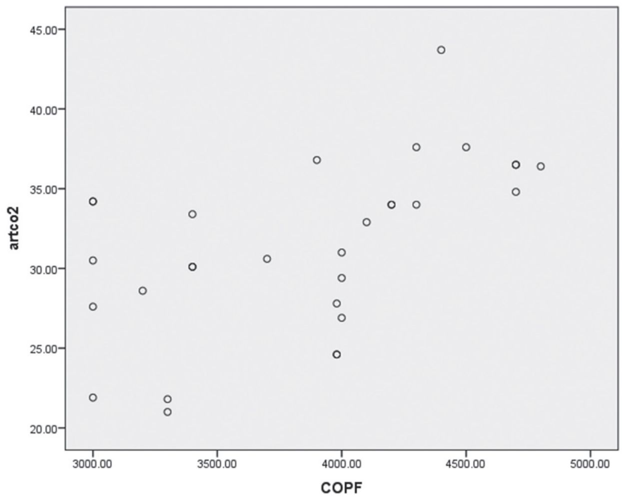

Figure 3. *Correlation between CO and $PaCO_2$.*

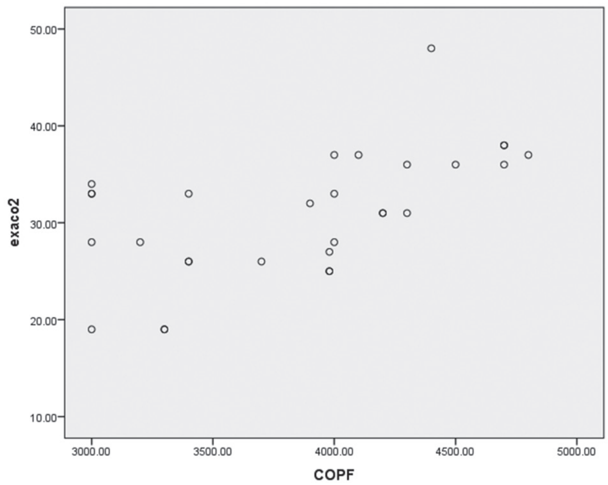

Figure 4. *Correlation between CO and $PECO_2$.*

Discussion

According to the results obtained in this study, there was a significant relationship between $PaCO_2$ and $PECO_2$ in CPB device (p = 0.001) and so it could be said that by measuring $PECO_2$, $PaCO_2$ can be estimated indirectly. Baraka et al. [9], in a study showed that by measuring $PECO_2$ by a suitable method, the $PaCO_2$ can be estimated.

According to the results of the study, there was a significant relationship between FGF and $PaCO_2$ (p = 0.016), and, FGF and $PECO_2$ in the CPB device (p = 0.04), this might be explained that by increasing FGF the amount of CO_2 pressure was reduced.Kristiansen et al. [10], in a study, showed that oxygenator exhaust capnography is a simple, inexpensive, and reliable method for estimating $PaCO_2$ in all patients (adult or child) and at all relevant temperatures, this was in line with the current study results. In this study, there was no significant relation between FiO_2 and $PaCO_2$ (p = 0.88), FiO_2 and $PECO_2$ in

CPB. There was a significant relation between CO and $PaCO_2$ pressure ($p = 0.001$), CO and $PECO_2$ in the CPB device ($p = 0.001$).Alston et al. [11], in a study, showed that oxygenator exhaust capnography with acceptable reliability for controlling $PaCO_2$ in a cardiovascular bypass model could be used in a laboratory, this was in line with the current study.

Baraka et al. [9], in a study, showed that oxygenator exhaust capnography could be used as a tool to monitor $PaCO_2$ during the Normothermic period of cardiopulmonary bypass and also for corrected $PaCO_2$ with temperature in hypothermic phase, this was in line with the current study results.

Conclusion

The results of this study showed that there was a significant relationship between $PaCO_2$ and $PECO_2$ in the CPB device and under certain circumstances, it might be possible to use a capnometer which is a non-invasive and low-cost monitoring process instead of an arterial blood sample which was an invasive method. It is, therefore, recommended that a study with a larger sample size and with the control of all possible confounding factors and in multiple intervals as a multicenter study should be done.

Acknowledgment

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List of Abbreviations

CABG	Coronary artery bypass grafting
CPB	Cardiopulmonary bypass
FGF	Fresh gas flow
FiO_2	Fraction of inspired oxygen
$PaCO_2$	Arterial pressure of carbon dioxide
$PECO_2$	End tidal carbon dioxide

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None.

Declaration of conflicting interests

None.

Consent for publication

Consent for publication was taken from the patients.

Ethical approval:

The study was approved by the ethical committee of Ardabil University of Medical Sciences.

Author details

Vadood Norouzi[1], Mohammad Hasanpour[1], Sanaz Fouladi[1]

1. Department of Anesthesiology, Faculty of Medicine, Ardabil University of Medical Sciences, Ardabil, Iran

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